International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 24s, 2025
https://theaspd.com/index.php

Enhancing Soil Fertility Through Biochar Application: A Sustainable Approach to Management in Soybean-Wheat Cropping Sequence

Sadashiv D. Nimbalkar[1*], Dr. Vitthal K. Kauthale[2], Dr. Rahul A. Bahulikar[3] , Deepak S. Patil[4], Rohini Gade[5]
[1*,2,3,4,5]BAIF Development Research Foundation, Central Research Station, Urulikanchan, Tq. Haveli, Dist Pune 412 202, Maharashtra, India,
Email: sadashiv.nimbalkar@baif.org.in

Abstract:
Biochar is a carbon-rich organic product produced through the pyrolysis of crop residues. Its porous structure and high surface area contribute to excellent nutrient and water-holding capacity, as well as high cation exchange capacity in the soil. Due to its slow degradation, biochar can remain in the soil for more than 11 years, enhancing soil organic carbon over time.
The study reveals that biochar treated with biofertilizers (nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and potash-solubilizing bacteria) at a level of 5 tons/ha and 8tons/ha with a 25% reduced dose of recommended chemical fertilizers enhances grain in soybean and wheat respectively.
Reducing the use of chemical fertilizers by 25% can also help maintain soil health without compromising yields in soybean-wheat cropping sequence. Therefore, the application of microbial-treated biochar (enriched with biofertilizers) at 5 and 8 tons/ha, combined with a 25% reduced dose of recommended dose of chemical fertilizers, provides better results compared to untreated biochar (referred to as charcoal) and the exclusive use of chemical fertilizers across cropping seasons.
Kay Words: *Biochar, Charcoal, Cropping sequence, Biofertilizers, Microbial enriched*

INTRODUCTION:

Biochar is a carbon-rich material produced through the pyrolysis of organic biomass under low-oxygen conditions and is increasingly recognized for its potential benefits in agriculture. The study showed that combining rice husk biochar and NPK compound fertilizer improved soil physical properties: soil Organic carbon levels, soil porosity, and soil water retention levels, and reduced soil bulk weight (Cahyono et. al., 2024). Its porous structure also improves microbial colonization (Thies & Rillig, 2012) and supports long-term carbon sequestration, making biochar a sustainable tool in regenerative agriculture.
Given the importance of biochar, an on-station trial was conducted to assess its impact on soil fertility and the productivity of a soybean-wheat cropping sequence. Biochar was applied at rates of 5 and 8 tons per hectare, adjusted according to soil type and crop requirements. The study also sought to identify an optimal biochar application rate when combined with a reduced dose of chemical fertilizer, aiming to enhance nutrient efficiency and crop yield. By evaluating varying levels of biochar, this research aims to determine its effects on soil fertility and crop yield in a soybean-wheat rotation sequence.
The researchers are also indicated, the Biochar promotes soybean growth and increases soybean yield (Di Wu et.al, 2022) and the addition of rice husk biochar can increase the growth and yield of Soyabean (Amalia Tetrani Sakya,. et. al. 2023.) **.** The study shows compost and biochar significantly increased soil total organic carbon content (Leogrande et al., 2024)**.**

MATERIALS AND METHODS:

The trial on biochar application with a reduced dose of chemical fertilizers was conducted at the BAIF Development Research Foundation, Urulikanchan, Maharashtra. The experiment was carried out in sandy loam to medium black soil, characterized by medium water-holding capacity. A Randomized Block Design (RBD) was used, with 10 treatments, each replicated three times.
In this study, Wheat straw was used to prepare charcoal, as this residue is commonly available after crop harvest. The charcoal was produced using the combustion method in a kiln and then ground into powder using an 8 mm sieve with a pulverizer. The charcoal powder was subsequently treated with a microbial culture consisting each of 10% Nitrogen-Fixing Bacteria (Rhizobium japonicum),Phosphate-Solubilizing Bacteria (Priestia megaterium, Bacillus polymyxa), and Potash-Solubilizing Bacteria (Frateuria aurantia)

mixed in 100 liters of water and left to soak overnight. The microbial-enriched biochar was then partially dried under shade for 2 days, retaining 8-10 % moisture.

The microbial-enriched biochar was applied to the soil at rates of 5 and 8 MTha^{-1} and similarly untreated Biochar (referred as Charcoal) of same quantity was also applied in beginning. The biochar was broadcasted on the soil surface before sowing the crops. Since biochar remains in the soil up to 11 years after application (Xinyu Ding., 2023), therefore, it was applied only once at the beginning of crop sowing. The trial was conducted covering both the Kharif 2023 (soybean) and Rabi 2023-24 (wheat) seasons, in the same trial plots without disturbing the experimental design. The soybean Var: KDS-753 and wheat Var: Lokwan were used for sowing with seed rate 75 kgha^{-1} and 125 Kgha^{-1} respectively. To monitor soil moisture, a moisture meter was used every weekend. Based on the soil moisture content, flood irrigation was provided until the crops reached maturity.

The following parameters were recorded for both Soybean and Wheat:

- **Soybean**: Plant height, No. of branches, No. of pods per plant, Test weight of 100 grains, and grain and straw yield.
- **Wheat**: Plant height, No. of tillers, spike length, No. of grains per spike, test weight of 100 grains, and grain and straw yield.

Changes in soil chemical and biological properties before and after crop harvest were analysed from soil samples collected during both seasons. The data collected were statistically analysed using MS Excel (2010) and OPSTAT software. Plant samples were collected during harvesting stage and grain samples were collected post-harvest.

Additionally, the NPK content in plant biomass and grain was measured to assess nutrient uptake. Nitrogen uptake was estimated using Kjeldahl's method as described by Piper. Phosphorus was determined using the Vanado molybdate Phosphoric yellow color method, and potassium was estimated using a flame photometer, as outlined by Jackson.

Table-1: Treatment details

Tr. #	Treatments
1	Biochar @ 5 MTha^{-1} + 100 % RDF
2	Biochar @ 5 MTha^{-1} +75 %RDF
3	Biochar @ 8 MTha^{-1} + 100 % RDF
4	Biochar @ 8 MTha^{-1} + 75 % RDF
5	Charcoal @ 5 MTha^{-1} + 100 % RDF
6	Charcoal @ 5 MTha^{-1} + 75 % RDF
7	Charcoal @ 8 MTha^{-1} + 100 % RDF
8	Charcoal @ 8 MTha^{-1} + 75 % RDF
9	100% GRDF
10	Absolute control
Note: Biochar: Treated with bio fertilizers (Rhizobium, PSB, KSB) is mentioned as Microbial enriched Biochar. **Charcoal:** Un treated Bio fertilizer, Recommended Dose of Fertilizers with Farm Yard Manure	

RESULT AND DISCUSSION:

The soybean crop was cultivated during the Kharif season, with two types of inputs applied at varying doses. These included biochar treated with beneficial bacterial cultures, such as Nitrogen-Fixing Bacteria (Rhizobium japonicum), Phosphate-Solubilizing Bacteria (PSB), and Potash-Solubilizing Bacteria (KSB). In contrast, charcoal, used purely as a soil amendment, was not treated with any of these bacterial cultures. The porous structure of biochar, its high internal surface area, and its ability to adsorb soluble organic matter and nutrients are likely to provide a highly suitable habitat for microbes to colonize, grow, and reproduce, particularly for bacteria, actinomycetes and arbuscular mycorrhizal fungi (Thies & Rillig, 2012).

The study revealed that the application of microbial-enriched biochar at a rate of 5 MTha^{-1}, along with a 25 % reduction in the recommended dose of chemical fertilizer in soybean, resulted in the highest grain yield of 23.78 qha^{-1} and straw yield of 34.86 qha^{-1} and is at parwith T_9, as shown in Table 2. The treatment T_4 (Biochar @ 8 MTha^{-1} + 75% RDF) achieved a grain yield of 23.22 qha^{-1} and a straw yield of 34.07 qha^{-}

[1], which were comparable to the highest yields. Therefore, using biochar at a level of 5 MTha^{-1} with a 25% reduction in chemical fertilizer is not only more effective but also more economical compared to other treatments. The researcher explained that the soybean yield increased with biochar and that biochar had a positive, sustainable effect on soil properties and soybean root growth, providing a new cultivation measure for soil health and soybean production in continuous cropping (Di Wu et.al. 2022). The studies are also showed that biochar at the rate of 8 MTha^{-1} the highest weight per 100 seed (16.9 and 14.9 g) and grain yields (1304.0 and 1316.7 kgha^{-1}) in 2018 and 2019 cropping seasons respectively (Sodah, M. G,. et al,. 2023).

Table-2: Crop growth and yield of Soybean Glycine max (Kharif Season)

Tr #	Treatment Details	Plant Height (cm)	No. of branches	No. of pods per plant	Test Weight (100-grain wt/g)	Yield (qha^{-1})	Straw Yield (qha^{-1})
T1	Biochar @ 5 MTha^{-1} + 100 % RDF	62.8	5	69	14.19	22.88	31.13
T2	Biochar @ 5 MTha^{-1} +75 %RDF	67.5	6	77	14.43	23.78	34.86
T3	Biochar @ 8 MTha^{-1} + 100 % RDF	66.8	6	72	14.18	22.15	30.7
T4	Biochar @ 8 MTha^{-1} + 75 % RDF	63.2	6	76	14.13	23.11	34.07
T5	Charcoal @ 5 MTha^{-1} + 100 % RDF	64.2	6	75	13.76	22.12	29.58
T6	Charcoal @ 5 MTha^{-1} + 75 % RDF	64.8	5	74	13.26	20.84	28.16
T7	Charcoal @ 8 MTha^{-1} + 100 % RDF	61.7	6	67	13.65	18.46	25.52
T8	Charcoal @ 8 MTha^{-1} + 75 % RDF	63.6	5	67	13.37	19.38	26.91
T9	100% GRDF	67.2	6	69	13.84	23.09	31.54
T10	Absolute control	59.6	5	58	13.24	12.8	17.3
	SE(m)+	2.25	0.27	3.03	0.25	1.38	2.1
	CD at 5 %	NS	NS	9.07	0.76	4.14	6.3

Residual effect of Biochar on Wheat crop: To assess the residual impact of biochar, wheat (variety Lokwan) was sown during the Rabi season in undisturbed treatment plots that had previously received biochar. No additional biochar was applied during this planting season; only the recommended dose of chemical fertilizers was used, as shown Table 3.

The study revealed that the highest grain yield of 26.58 qha^{-1} in T_4 and the highest straw yield of 100.36 qha^{-1} T_3 were achieved in wheat, under the residual effect of microbial-enriched biochar that had been applied at 8 MTha^{-1} during soybean cultivation.

The recent studies shows that Biochar application has positive effects up to 30% on biomass production and yield (Vaccari et al., 2011) and the combined application of 125% RDF and Biochar @ 12 MTha^{-1} was found to record significant grain yield, straw yield (Jitendra Kumar Sharma,. 2022).

Table-3: Residual effect of Biochar on crop growth and yield of Wheat (Triticum aestivum) _Rabi Season

Tr #	Treatments	Plant Height (cm)	Spike length (cm)	No. of tillers	Test Weight (100 grain wt. in g)	Yield (qha^{-1})	Straw Yield (qha^{-1})
T1	Residual effect of Biochar @ 5 MTha^{-1} + 100 % RDF	69	7.4	7	4.2	24.46	79.95

T2	Residual effect of Biochar @ 5 $MTha^{-1}$ +75 %RDF	66.4	6.6	8	4	24.11	65.55
T3	Residual effect of Biochar @ 8 $MTha^{-1}$ + 100 % RDF	72.2	7.6	8	4.1	24.97	100.36
T4	Residual effect of Biochar @ 8 $MTha^{-1}$ + 75 % RDF	69.8	7.5	7	4.7	26.58	90.07
T5	Residual effect of Charcoal @ 5 $MTha^{-1}$ + 100 % RDF	69.7	7.2	8	4	25.1	89.07
T6	Residual effect of Charcoal @ 5 $MTha^{-1}$ + 75 % RDF	68.7	7.2	7	3.7	24.26	85.27
T7	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 100 % RDF	64.1	7.4	8	4.4	24.39	84.14
T8	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 75 % RDF	67.9	7.1	7	3.7	21.2	86.67
T9	100% GRDF	70.3	7.3	7	4	24.17	87.71
T10	Absolute control	58.8	6.5	6	2.7	13.86	95.92
	SE(m)+	0.75	0.15	0.21	0.16	1.59	5.17
	CD at 5 %	2.25	0.46	0.64	0.47	4.77	15.47

Soil chemical analysis: Soil chemical analysis was conducted after the wheat crop harvest, and the results are presented in Table 4. Under the residual effect of microbial-enriched biochar 0 $MTha^{-1}$ combined with 75% RDF (Applied 8 $MTha^{-1}$ + 75 % RDF to Soybean crop during Kharif), the soil organic carbon increased by 0.14 % compared to the control. Recent studies have shown that 39–51% of biochar remained in the top 30 cm of soil after 11 years (Xinyu Ding, 2023), indicating its long-lasting presence and potential as a soil amendment. Additionally, biochar was found to increase soil organic carbon (SOC) at depths of 20–40 cm (Ma et al., 2023), suggesting that its effects can persist over time and contribute to soil health deeper in the profile.

Table-4: Soil chemical analysis (After harvesting of Wheat) _Rabi Season

Treatments	pH	EC	OC (%)	N ($kgha^{-1}$)	P ($kgha^{-1}$)	K ($kgha^{-1}$)
Initial Soil Status	7.56	0.42	0.45	121.25	28.33	184.58
After harvesting						
Residual effect of Biochar @ 5 $MTha^{-1}$ + 100 % RDF	7.11	0.26	0.62	124	24	180
Residual effect of Biochar @ 5 $MTha^{-1}$ +75 %RDF	7.12	0.29	0.63	132	23	185
Residual effect of Biochar @ 8 $MTha^{-1}$ + 100 % RDF	7.22	0.76	0.63	125	22	190
Residual effect of Biochar @ 8 $MTha^{-1}$ + 75 % RDF	7.08	0.60	0.65	132	20	185
Residual effect of Charcoal @ 5 $MTha^{-1}$ + 100 % RDF	7.14	0.43	0.64	132	21	185
Residual effect of Charcoal @ 5 $MTha^{-1}$ + 75 % RDF	7.42	0.58	0.63	126	20	200
Residual effect of Charcoal @ 8 $MTha^{-1}$ + 100 % RDF	7.45	0.52	0.64	126	22	205
Residual effect of Charcoal @ 8 $MTha^{-1}$ + 75 % RDF	7.3	0.48	0.64	130	19	200
100% GRDF	7.35	0.47	0.52	132	22	205
Absolute control	7.15	0.32	0.51	128	20	210

Nutrient uptake by Soybean: The uptake of nitrogen (188.83 kgha^{-1}), phosphorus (102.62 kgha^{-1}), and potassium (68.02 kgha^{-1}) also increased in Soybean with the use of microbial-enriched biochar application at the level of Biochar 5 MTha^{-1}+75 % RDF in T_2. This demonstrates that treating biochar with bio fertilizers enhances plant growth and yield while reducing the need for chemical fertilizers by 25%.
The increased grain and straw yields can be attributed to the slow release of nutrients (NPK) from the biochar, providing plants with nutrients as needed. This effect is further supported by the beneficial microbes introduced through biochar treatment (Table 5), which enhance nutrient availability and promote plant growth. Study conducted by researchers shows that ,Co-inoculation of B. japonicum with P. putida and 3% biochar significantly improved the growth and nutrient content of soybean and the level of nutrients and enzymes in the soil, thus making the soil more fertile to support crop yield (Jabborova et al., 2020).

Table-5: Nutrient uptake by Soybean (Glycine max)

#	**Treatment details**	**Nutrient uptake (kgha^{-1})**		
		N	**P**	**K**
T 1	Biochar @ 5 MTha^{-1} + 100 % RDF	181.48	82.64	64.81
T 2	Biochar @ 5 MTha^{-1} +75 %RDF	188.83	102.62	68.02
T 3	Biochar @ 8 MTha^{-1} + 100 % RDF	186.05	91.44	80.34
T 4	Biochar @ 8 MTha^{-1} + 75 % RDF	183.53	94.91	80.05
T 5	Charcoal @ 5 MTha^{-1} + 100 % RDF	173.19	84.27	73.93
T 6	Charcoal @ 5 MTha^{-1} + 75 % RDF	158.75	79.86	51.94
T 7	Charcoal @ 8 MTha^{-1} + 100 % RDF	158.77	68.61	54.54
T 8	Charcoal @ 8 MTha^{-1} + 75 % RDF	156.94	57.87	54.17
T 9	100% GRDF	170.99	76.48	66.65
T 10	Absolute control	99.91	45.74	37.31
	SE(m)+	4.42	2.08	1.74
	CD at 5 %	13.23	6.25	5.2

Nutrient uptake by Wheat: This residual effect of microbial-enriched biochar (0 MTha^{-1} combined with 100 % RDF) also resulted in higher biomass yield (100.36 qha^{-1}) and grain yield (24.97 qha^{-1}) in wheat compared to the recommended dose of fertilizers alone (Table-6). The residual impact of microbial-enriched biochar significantly enhances wheat production, surpassing the performance of consistent chemical fertilizer use in a soybean-wheat cropping sequence. Similarly, the study reveals that the residual effect of Biochars with different doses of fertilizer application improved plant growth parameters and test (Panda et al., 2021) and increased N uptake of plants in all soil with N or P supply(Egamberdieva et al., 2022).

Table-6: Nutrient uptake by Wheat (Triticum aestivum)

Treatments	**Treatment details**	**Nutrient uptake (kgha^{-1})**		
		N	P	K
T 1	Residual effect of Biochar @ 5 MTha^{-1} + 100 % RDF	112.77	79.35	61.6
T 2	Residual effect of Biochar @ 5 MTha^{-1} +75 %RDF	96.84	69.04	52.9
T 3	Residual effect of Biochar @ 8 MTha^{-1} + 100 % RDF	154.16	97.76	73.95
T 4	Residual effect of Biochar @ 8 MTha^{-1} + 75 % RDF	149.32	93.32	71.16
T 5	Residual effect of Charcoal @ 5 MTha^{-1} + 100 % RDF	133.59	90.2	70.79
T 6	Residual effect of Charcoal @ 5 MTha^{-1} + 75 % RDF	117.2	79.96	61.34

T 7	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 100 % RDF	113.96	80.32	60.78
T 8	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 75 % RDF	106.79	80.9	64.72
T 9	100% GRDF	134.26	89.5	70.48
T 10	Absolute control	128.44	86.72	65.87
	SE(m)+	6.05	4.18	3.22
	CD at 5 %	18.2	12.53	9.65

Beneficial effects of microbial-enriched Biochar: The study highlights the beneficial effects of microbial-enriched Biochar in enhancing soil microbial populations and improving plant nutrient uptake. Specifically, the inclusion of Nitrogen-Fixing Bacteria (Rhizobium japonicum), Phosphate-Solubilizing Bacteria (PSB), and Potash-Solubilizing Bacteria (KSB) in Biochar led to a significant increase in the counts of Bacteria, Actinomycetes, and Fungi when compared to the control and even to pure Biochar (referred to as charcoal). This indicates that microbial-enriched Biochar can foster a more active microbial community in the soil (Table-7). Additionally, when microbial-enriched Biochar was applied at 5 $MTha^{-1}$ with 75% of the Recommended Dose of Fertilizers (RDF) for soybean, and residual effect of Biochar at 0 $MTha^{-1}$ with 100 % RDF for wheat, there was a significant improvement in nutrient uptake. These enhanced nutrient uptakes contributed to increased grain and biomass yields in Soybean (Table-2), by microbial enriching biochar help to nutrient uptake and fostering a healthier soil ecosystem, this integrated method not only improves the productivity of soybean and wheat crops but also supports long-term soil health and environmental sustainability.

Table-7: Change in microbial populations in the soil after Wheat (Triticum aestivum) Rabi season.

Tr#	Treatments Details	Total Viable Count CFU/gm		
		Bacteria	Actinomycetes	Fungi
T1	Residual effect of Biochar @ 5 $MTha^{-1}$ + 100 % RDF	3×10^5	2×10^5	2×10^5
T2	Residual effect of Biochar @ 5 $MTha^{-1}$ +75 %RDF	5×10^5	2×10^5	2×10^5
T3	Residual effect of Biochar @ 8 $MTha^{-1}$ + 100 % RDF	3×10^5	1×10^5	2×10^5
T4	Residual effect of Biochar @ 8 $MTha^{-1}$ + 75 % RDF	6×10^5	1×10^5	2×10^5
T5	Residual effect of Charcoal @ 5 $MTha^{-1}$ + 100 % RDF	1×10^5	1×10^4	4×10^4
T6	Residual effect of Charcoal @ 5 $MTha^{-1}$ + 75 % RDF	2×10^5	1×10^4	1×10^4
T7	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 100 % RDF	5×10^4	1×10^3	4×10^4
T8	Residual effect of Charcoal @ 8 $MTha^{-1}$ + 75 % RDF	2×10^5	3×10^4	3×10^4
T9	100% GRDF	1×10^5	2×10^4	1×10^4
T10	Absolute control	8×10^4	2×10^3	3×10^3

CONCLUSION:

Based on the results, it is recommended that the biochar treated with biofertilizers (Nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and potash-solubilizing bacteria) and a 25% reduced recommended dose chemical fertilizers can enhance nutrient uptake, leading to increased grain and straw yields in a soybean-wheat cropping sequence.

Reducing the consistent use of chemical fertilizers by 25% may also help to maintain soil health without compromising grain and straw yields in soybean-wheat cropping sequence which generally followed in rainfed agriculture.

Therefore, the application of microbial-treated biochar (with bio fertilizers) at 5 $MTha^{-1}$, combined with a 25% reduced recommended dose of chemical fertilizers in Soyabean and residual effect of biochar at the level of residual effect of Biochar @ 8 $MTha^{-1}$ + 75 % RDF in wheat, shows better results compared to untreated biochar (referred to as charcoal) and the exclusive use of chemical fertilizers.

Acknowledgement:
The authors are thankful to Research Coordination Committee (RCC), BAIF Development Research Foundation, Pune, for financial support to conduct the study and thankful to the Scientists Dr. A. B. Pande, Dr. J. R. Khadse, Mr. P. S. Takawale, Dr. R. A. Bahulikar, Mr. S. S. Jade, Dr. M. J. Aware, Ms. S. N. Kale, Mr. P. R. Rajwade, Mr. A. H. Malav and other research team members at BAIF Development Research Foundation, Central Research Station, Urulikanchan, Ta. Haveli, Dist. Pune 412 202 M.S. (India) for cooperation and guidance.

REFERENCES:

1. Amalia Tetrani Sakya1, Muji Rahayu1, Samanhudi1, Gani Cahyo Handoyo1, and Muhammad Dio Nugroho Anindra Putra (2023),. Growth and yield of soybean varieties with biochar application, E3S Web of Conferences 467, 01020 (2023). https://doi.org/10.1051/e3sconf/202346701020
2. Di Wu, Weiming Zhang, Liqun Xiu, Yuanyuan Sun, Wenqi Gu, Yuning Wang, Honggui Zhang and Wenfu Chen,(2022),.Soybean Yield Response of Biochar-Regulated (Soil Properties and Root Growth Strategy, Agronomy 2022, 12, 1412. https://doi.org/ 10.3390/agronomy12061412
3. Egamberdieva, D., Ma, H., Reckling, M., Omari, R. A., Wirth, S., & Bellingrath-Kimura, S. D. (2022),. Interactive effects of biochar, nitrogen, and phosphorous on the symbiotic performance, growth, and nutrient uptake of soybean (Glycine max l.). Agronomy, 12(1). https://doi.org/10.3390/agronomy12010027
4. F.P. Vaccari, S. Baronti,E. Lugato, L. Genesio · S. Castaldi, F. Fornasier · F. Miglietta,. (2011),. Biochar as a strategy to sequester carbon and increase yield in durum wheat, European Journal of Agronomy, Volume 34, Issue 4, May 2011, Pages 231-238. https://www.sciencedirect.com/science/article/abs/pii/S1161030111000086.
5. Jitendra Kumar Sharma, RH Meena, Gajanand Jat and Abhitej Singh Shekhawat,.(2022),. Effect of fertility levels and biochar on yield of wheat (Triticum aestivum L.), The Pharma Innovation Journal 2022; 11(7): 3590-3594. https://www.thepharmajournal.com/archives/2022/vol11issue7/PartAS/11-7-437-360.pdf.
6. Jabborova, D., Wirth, S., Kannepalli, A., Narimanov, A., Desouky, S., Davranov, K., Sayyed, R. Z., Enshasy, H. El, Malek, R. A., Syed, A., & Bahkali, A. H. (2020),. Co-inoculation of rhizobacteria and biochar application improves growth and nutrientsin soybean and enriches soil nutrients and enzymes. Agronomy, 10(8). https://doi.org/10.3390/agronomy10081142
7. Leogrande, R., Vitti, C., Castellini, M., Garofalo, P., Samarelli, I., Lacolla, G., Montesano, F. F., Spagnuolo, M., Mastrangelo, M., & Stellacci, A. M. (2024). Residual Effect of Compost and Biochar Amendment on Soil Chemical, Biological, and Physical Properties and Durum Wheat Response. Agronomy, 14(4), 1–18. https://doi.org/10.3390/agronomy 14040749
8. Ma, R., Wu, X., Liu, Z., Yi, Q., Xu, M., Zheng, J., Bian, R., Zhang, X., & Pan, G. (2023),. Biochar improves soil organic carbon stability by shaping the microbial community structures at different soil depths four years after an incorporation in a farmland soil. Current Research in Environmental Sustainability, 5(January). https://doi.org/10.1016/j.crsust.2023.100214
9. Cahyono, S Maro'ah, S Minardi, V R Cahyani , Sudadi, I Ismiliyawati, (2024),.10th International Conference on Sustainable Agriculture and Environment, IOP Conf. Series: Earth and Environmental Science 1362 (2024) 012004, https://iopscience.iop.org/article/10.1088/1755-1315/1362/1/012004/pdf
10. Panda, A., Srivastava, L. K., Sonboir, H. L., & Jatav, G. (2021),. Residual effect of biochar application on growth parameters of wheat. 10(1), 557–560.
11. Sodah, M. G., O. J. Jayeoba, S. M. Amana and I. M. Jibrin,.(2023),. Growth and yield of soybean (Glycine max. Merrill) as influenced by biochar application, Production Agriculture and Technology (PAT), 2022; 18(2): 50-58 ISSN: 0794-5213. http://www.patnsukjournal.net/Vol18No2/P7.pdf
12. Thies, J. E., & Rillig, M. C. (2012). Characteristics of biochar: Biological properties. Biochar for Environmental Management: Science and Technology, March, 85–105. https://doi.org/10.4324/9781849770552.
13. Xinyu Ding, Guitong Li, Xiaorong Zhao, Qimei Lin and Xiang Wang,.(2023),. Biochar application signifcantly increases soil organic carbon under conservation tillage: an 11-year field experiment, Ding et al. Biochar (2023) 5:28. https://link.springer.com/article/10.1007/s42773-023-00226-w